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A Comparative Study to Assess the Energy Efficiency of Temporary Structures to Guarantee Emergency Basic Healthcare in Italy

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Abstract: During emergencies, healthcare is generally provided by tents and temporary shelters, without considering the environmental and social impact of the structures as a priority, in favor of swift response. The resultant constructions intended as a temporary solution often persist for a long time. This paper aims to analyze an alternative and innovative modular structure designed as a transitory solution in emergencies and everyday life. The aim of this study is to assess and compare the energetic performance of a modular adaptive model for basic healthcare for people who are not subscribed to the Italian National Health System. The main goal is to challenge standard models by proposing a new model able to diminish the weaknesses of the current sanitary models, to improve the social conditions, flexibility and energy efficiency, and the thermal comfort of the occupants. In the first part of the paper, the conceptual framework and the preliminary design of the model are described by investigating the benefits of a safe space as a generator space for care services and the community. In the second part, the technological requirements of the system are defined by comparing the use of different panel structures and low-impact technologies. The energy efficiency and environmental impact of the model are assessed by comparing several panel structures in two different climatic areas in Italy (northern and Mediterranean areas) using SketchUp and EnergyPlus simulation. As a result, different configurations of the model are proposed according to the different climatic areas in order to optimize the model, from both an architectural and a technological point of view (box and panel composition).

Keywords: emergency buildings; sustainability; energy simulation

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1. Introduction

This paper aims to study the adaptation of a system designed as a healthcare center for destitute and irregular immigrants in Italy in emergencies, such as flooding and earthquakes, in different regions of the country.

Nowadays, climate change and changing geopolitical dynamics are generating emergencies across the world, forcing people to abandon their own houses and live in refugee camps or inadequate situations. To respond to these phenomena, countries are trying to address the challenges of designing emergency buildings, seeking to meet the needs of the situation to guarantee acceptable living conditions as a matter of human rights.

There are a multitude of studies focusing on the use of modular construction for emergency situations. A literature review has provided an overview of emergency models and experiences in past and recent studies. In the last twenty years, several strategies and innovations have been proposed to ensure the provision of healthcare facilities during and following disaster events [1].

According to a UNISDR report [2], Italy is one of the countries in the world most affected by natural catastrophes. The variety of the territory creates a range of issues, including systemic and hydrogeological risks and volcanic risks. Due to the humanitarian crisis occurring in Mediterranean areas in past decades, Italy has become a center of attraction for people seeking shelter from their situations.

An emergency is defined as a rapid modification of urban spaces to accommodate temporary settlements to respond to people's needs, and which can result from different causes. For example, the Middle East and Africa are known for humanitarian emergencies, while the global East and Caribbean are known for climate emergencies [3]. Countries have tried to face the challenge of building emergency features that consider sustainability in their design. Examples include the refugee camps of Al-Azarq [4], working only with renewable energy. Generally speaking, research is now moving in this direction, reflecting the reality that temporary solutions usually become permanent for the lifetime of the people involved.

The Italian territory has become interested in emergencies, such as earthquakes or flooding, that have been solved using primary emergency modules, such as shelters and containers [5,6].

In literature reviews, three main types of emergency structures have been identified that are used to address the need for accommodation due to catastrophic events or sanitary emergencies: emergency shelters, temporary shelters, and temporary housing [7–9].

Emergency and temporary shelters include waterproof and windproof structures. Those available on the market are usually made of polyester materials, but in the literature, it is possible to find examples made from cotton and modacrylic [4]. Nowadays, shelters are the most used technology for temporary emergency events. Currently, they are recognized as the most sustainable emergency solution due to their flexibility and adaptability as they provide a highly standardized solution. However, their extensive use in urban areas can generate an alienating environment that disregards cultural and social norms. The speed of construction is optimal, but shipping transportation can take a long time [10]. Also, such solutions can be expensive compared to other systems. In recent years, several international researchers have studied the thermal behavior of temporary shelters used by various humanitarian organizations in emergency situations [11,12]. In Mediterranean and hot climates, the design approach is oriented towards passive design and the use of environmental resources, like natural ventilation, to obtain comfortable indoor living conditions. It has emerged that below 7 °C, a passive design approach is not sufficient to guarantee acceptable comfort conditions, with HVAC systems often having to be used. In these studies, it is highlighted that the external envelope—generally curtains made of cotton—is very lacking in terms of thermal insulation, air and water resistance, and has high thermal conductivity values.

Cornaro et al. [13] and Lv T. et al. [14] studied the implementation of this typology with PV technology considering internal comfort, though it is rare to find such solutions on the market. Such structures may have a range of dimensions, but the structure itself is inflexible. Moreover, the well-being of the users is compromised.

A second category of emergency modules is represented by temporary houses that are designed to ensure the provision of services and a good quality of life over an extended period of time. During the last century, the evolution of these modules has reflected the development of prefabrication techniques [15]. Montalbano and Santi [8] examined the sustainability of temporary housing in a post-disaster scenario. In the study, each typology was classified according to a specific period of stay. For immediate emergencies and over a very brief period (12–48 h after the disaster), emergency shelters are used. Temporary shelters can be used for a duration ranging from 2 to 30 days. For long periods, depending on the severity of the disaster, temporary housing is used, generally from 3 months to 5 years or even longer.

The evolution of temporary housing relies significantly on advancements in prefabrication technology. The selection of a prefabrication system has both economic and environmental implications, influenced by transportation dimensions and logistics costs [16].

A widely adopted type of prefabricated temporary housing is the container, a solution standardized in 1967 by UNI (Italian Standards Organization) with ISO 668:2020, which has since become a universally recognized standard. The primary advantage of containers is their rapid installation and adaptability to various contexts, owing to the standardization of a multipurpose metal parallelepiped. This concept was pioneered by American entrepreneur Malcolm Purcell McLean in the 1960s and 1970s [17,18]. However, despite their significant utility in post-disaster scenarios, containers are not environmentally or socially sustainable [19]. Currently, four categories of containers are available on the market. Each category features a load-bearing component and a carried component, with variations in envelope composition that are unique to each container type [7]. The energy efficiency of these systems is notably limited due to poor insulation. Moreover, their flexibility is constrained as they do not account for environmental conditions, cultural aspects, or location-specific needs [20].

Temporary housing has been deployed in two significant events in Italy: the L'Aquila (2009) and Emilia Romagna (2012) earthquakes. A critical issue in these deployments was meeting energy efficiency standards for building envelopes [18]. To address these requirements, several technological solutions were proposed, including the use of concrete structural panels with added insulation layers, such as rock wool panels. Other solutions involved container modules enhanced with an additional insulating layer.

In their study, Moon et al. [21] highlighted the importance of factors such as climate, structure, material, and lifespan for temporary housing, particularly concerning structural aspects. Several studies [22–24] emphasize the importance of incorporating net-zero energy standards in the passive and active designs of modular buildings. The relationship with different climatic zones is crucial, as environmental inputs are highly significant for modular structures. Zubair et al. [25] demonstrated that installing PV panel-based roofs can reduce cooling loads in hot climates by 12.3%.

The COVID-19 pandemic posed a unique and urgent challenge that necessitated the rapid construction of temporary hospitals, presenting a significant challenge to the construction industry [26,27]. In these temporary hospitals, functional zoning layouts were crucial in preventing contamination between infected and non-infected areas [28].

An advanced form of temporary housing technology is represented by modular prefabricated panel solutions. This approach, based on small prefabricated components, optimizes transportation and allows for user customization by offering various shapes that can adapt to diverse cultural, thermal, and typological requirements. Additionally, technological flexibility is enhanced through assisted self-construction, enabling users to build their own houses.

A dynamic building envelope must be adaptable to different climatic conditions and capable of interacting with environmental inputs. Moreover, the availability of local resources is a crucial factor, as it pertains to materials and components that are readily accessible in the area.

The design of modular systems must consider both user needs and different emergency contexts [22], ensuring suitability across various locations and climatic conditions. Paparella and Caini [7] present an innovative design for a modular prefabricated panel system.

To evaluate the affordability of the model, Table 1 compares traditional solutions, such as emergency tents and shelters, with the proposed modular panel model. The table defines the prototype system in comparison to primary emergency building solutions, assigning a score from 1 to 3, with 1 indicating the least alignment and 3 indicating the closest alignment with the specified requirements.

Sustainability and innovation are assessed based on several criteria: energy efficiency and adaptability to renewable energy sources, internal and psychological comfort of users, flexibility regarding external contexts, system implementation, and internal functional space composition and relations. Finally, the speed of construction and economic evaluation are considered, as these structures need to be assembled and operational in the shortest time possible due to the nature of emergencies.

Table 1. The table visually summarizes the comparison among emergency structures.

		Emergency Shelters	Temporary Shelter	Temporary Housing: Containers	Temporary Housing: Panels
Sustainability	Energy efficiency	1	2	1	to be assessed
	Renewable implementation	2	3	1	2
	Indoor quality	1	2	1	to be assessed
Flexibility	Adaptability to external conditions	1	1	1	3
	Implementation and composition of the system	1	2	2	3
Construction	Speed of Construction	3	2	3	2
	Economic solutions	3	2	3	1

2. Materials and Methods

The aim of this study is to assess and compare the energy performance of a modular adaptive model designed for basic healthcare services for individuals not enrolled in the Italian National Health System. This model has been previously described and presented in [28]. The primary objective of the emergency module is to surpass standard models by offering a new design that addresses the weaknesses of current healthcare models, thereby improving social aspects, flexibility, energy efficiency, and thermal comfort for occupants. Unlike other models of emergency healthcare structures (e.g., first aid, COVID-19 facilities), this study proposes a flexible model adaptable to various contexts and conditions across Italy, with a projected lifespan of approximately ten years and the potential for repurposing.

The main steps of the research methodology are as follows (Figure 1):

- Model definition. This initial phase describes the conceptual framework and preliminary design for non-conventional healthcare spaces, highlighting the benefits of a secure space as a foundational element for care services and community engagement.
- Technology definition. This phase outlines the technological requirements and configurations of different box and platform setups.
- Energy simulations. In the final phase, the thermal performances of the model are analyzed by comparing various panel structures in two distinct climatic regions of Italy: Bolzano (representative of the cold area) and Palermo (representative of the hot Mediterranean area). The simulations were conducted using SketchUp 2023 and EnergyPlus V23-2-0 software, delineating two thermal zones—the box and the platform—and analyzing the passive contributions derived from their interaction.

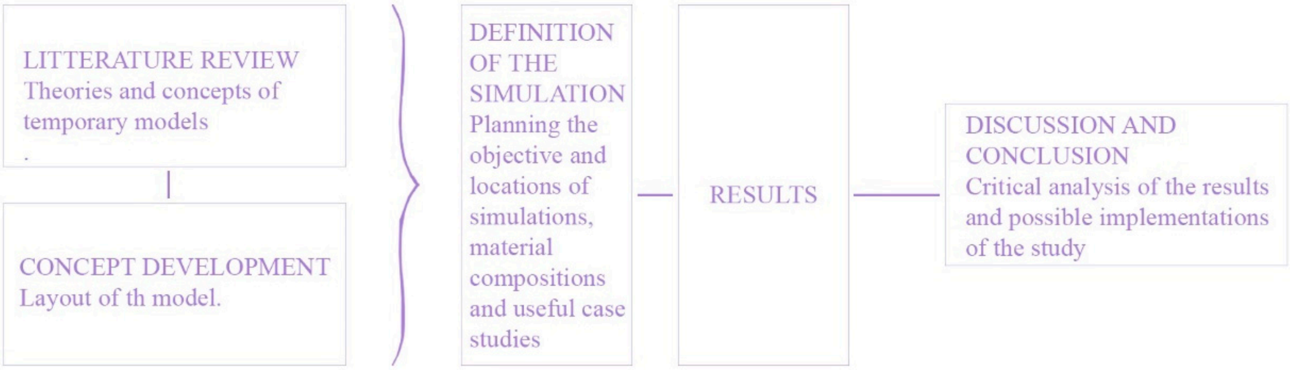


Figure 1. Flowchart of the methodology.

3. Model Definition

Health is a reflection of our quality of life, encompassing the well-being derived from an individual's integration into society rather than existing on its periphery. The World Health Organization (WHO) [29] identifies health determinants as factors related to the social and economic environment, the physical environment, and the individual environment.

Among these, the physical environment and social support networks are considered the primary influences. The physical environment includes safe housing and communities, while the social support networks encompass families, friends, and community connections.

Special attention is given to communal and medical spaces, which are regarded not only as healthcare facilities but also as environments that promote the lifestyles of individuals once their immediate medical treatment concludes. Consequently, the model underscores the significance of spaces dedicated to socialization, aiming to create environments where schools and associations can bolster local communities.

In Italy, access to basic healthcare is a constitutional right, as stipulated in Article 32 of the Italian Constitution. This right is also supported by Article 25 of the Universal Declaration of Human Rights, endorsed by the United Nations.

3.1. Conceptual Framework: The Architecture

The concept of the emergency model emerged concurrently with the needs identified during analyses of healthcare facilities for destitute and undocumented immigrants. Approximately 20 cooperatives and private social associations currently operate in Italy, not only delivering basic healthcare cures but also helping the progress of the Foreigners Temporarily Present code, thereby facilitating access to national health facilities.

The initial phase of the analysis involved direct surveys conducted by existing associations that provide healthcare access to undocumented immigrants and the destitute, aiming to obtain a comprehensive user need analysis [28].

During data collection, several interviews were conducted to ascertain the importance of additional social spaces. All interviewed associations confirmed the need for social spaces beyond therapeutic settings. Consequently, the model incorporates requirements for psychological support as private spaces where individuals can receive professional help, as well as external spaces. Interviews with the Private Associations were conducted in 2022. Medical professionals were queried about the aforementioned topics. The Private Associations participating in the initiative were located in the Emilia-Romagna region (the Biavati Association of Bologna, Caritas of Ferrara, Caritas of Reggio Emilia, and the Sokos Association of Bologna) and in the Marche region (Caritas of Senigallia). Beginning in December 2023, thanks to the efforts of these associations, volunteers working in refugee education, and Refugees Welcome, it was possible to collect questionnaires from refugees and undocumented immigrants. These questionnaires confirm the necessity of community support and highlight the psychological issues caused by social status, violence, and loneliness.

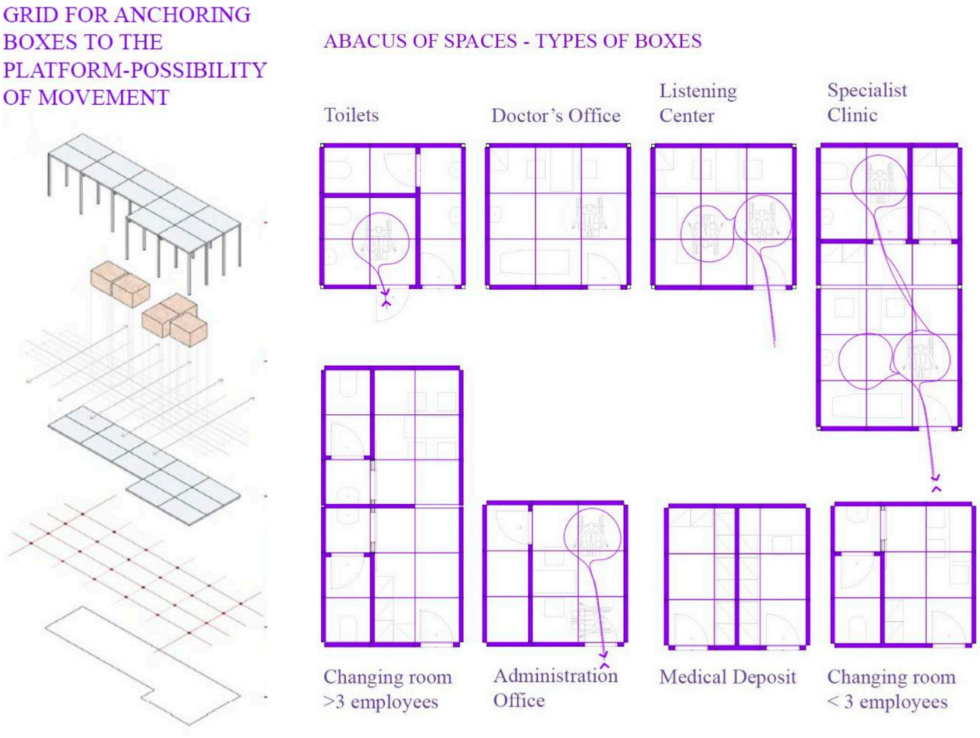
Each space has been designed according to appropriate architectural, technical, and privacy requirements.

The design principle begins with the idea of bypassing the conventional hospital structure by implementing social aggregation spaces as connectors, transforming traditional corridors and waiting areas into junctions and crossing points.

As undocumented immigrants often reside at the margins of society and rarely have opportunities to interact with others, emergency victims also need functional spaces where they can develop resilience and foster a sense of community, spending time with people who can positively impact their mental health. Therefore, a common area is proposed to replace the traditional corridor model. This area is integrated throughout the clinical spaces, providing opportunities to create a social network and interact with other associations and schools working in the area to promote social inclusion and support.

The model proposes a multi-functional, open-space design divided into several "macro-areas." Each common open space connects to enclosed areas where people can meet and interact, avoiding a rigid, mono-functional design approach. The model aims to foster resilience among users, who are often in difficult situations and suffering from loneliness. As Hay et al. define in planning resilient communities, resilience involves not opposing change but managing and responding to it, supporting society during its recovery [30].

Figure 2a illustrates the modular grid, which is useful for progressively aggregating spaces and adapting to different contexts.



(**a**) (**b**)

Figure 2. Conceptual framework of the model (platform–box) and example of the basic modules. (**a**) An exemplification of the grid is presented. The image shows how the enclosed box spaces interact with the open space of the platform, which serves as the common area. (**b**) The abacus of spaces is presented. The main services the structure must provide are designed based on the survey analysis conducted with the associations.

Specifically, the model is divided into two components based on the concept's needs:

- The common space: this area is flexible and adaptable to the lot's dimensions, fluxes, and shape. It functions as an internal-external space, as no HVAC is needed (no thermal zone).
- The box space: These are the proper modules designed to provide medical care. The box organization includes different medical offices, such as general practitioner offices, gynecologist offices, and psychological and psychiatric offices. An abacus for the main offices is provided (Figure 2b). During the design process, the position of boxes considered Hall's definition of interpersonal distance [31], with designs varying according to the needed levels of privacy. The boxes are equipped with heating and wiring.

The grid is based on a module of 1.25 m, with the aggregation of modules based on 3 × 3 or 6 × 3 m, in compliance with sanitary space requirements. This defines an abacus of spaces. Flexibility and progressive implementation of the design are possible, allowing for a nearly infinite number of configurations adaptable to different contexts (Figure 3). Configurations can range from a minimum setup (for emergencies or extreme sanitary events) to a maximum module configuration that includes all necessary services (e.g., expansion of existing structures).

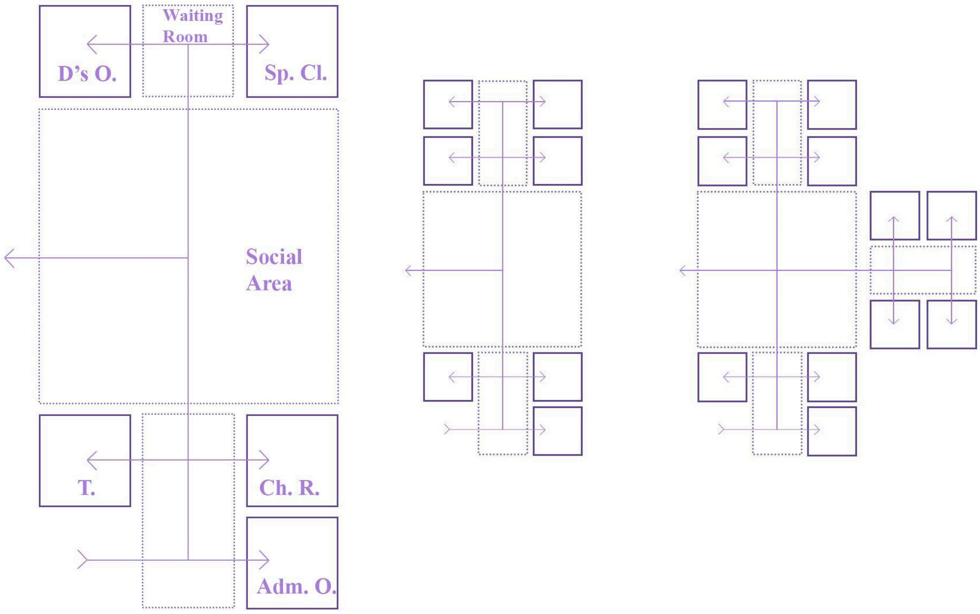


Figure 3. Conceptual framework of possible model configuration. The image illustrates the basic configuration of the project. It is essential to place services such as toilets, changing rooms, and administration offices near the entrance. The social area then acts as a connector between the entrance and the primary medical services. Thanks to the grid presented in Figure 2a, it is possible to implement the services modularly.

3.2. Technological Framework: Definition of the Prototype and Requirements

The technological design has been developed to meet the requirements of flexibility, construction speed, and low environmental impact, using dry prefabricated elements to be assembled on-site.

The platform and the box have two distinct but complementary technological designs based on prefabricated systems that can be reused and reassembled. This approach is advantageous for several reasons: firstly, it accommodates the limited budgets of private social associations; secondly, it addresses the need to expand or relocate the structure after an estimated period of 5 to 10 years due to changes in migration flows and seasonal work.

The platform, which serves as the common area, is a modular steel structure composed of elements sized 585 × 385 cm. The floor slab consists of prefabricated wooden panels anchored off-site to an embossed metal sheet; the final prefabricated panel is ready for on-site assembly in elements measuring 128 × 280 cm. A steel frame structure supports translucent polycarbonate panels measuring 50 cm, which can be opened or removed.

Boxes are placed on the platform's modular grid (Figure 4b) using a steel frame supporting structure. The walls are prefabricated sandwich panels measuring 3 × 6 or 3 × 3 m.

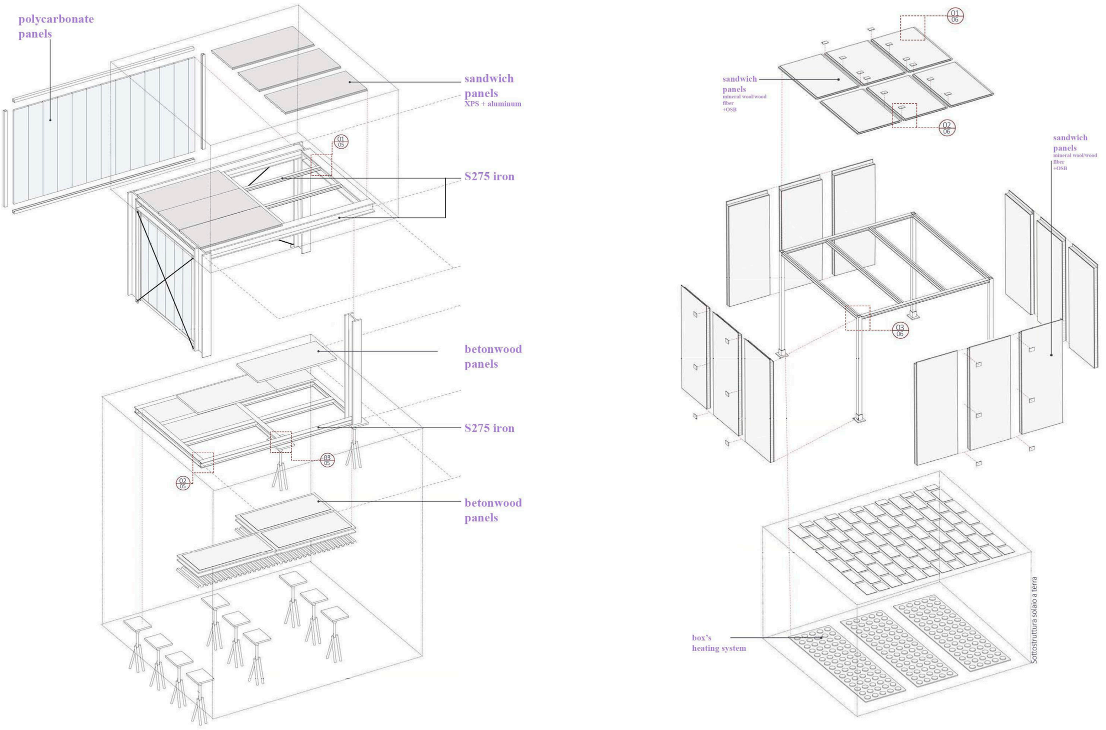
Platforms and boxes are structurally independent systems.

Sandwich panels can be customized according to the geographic area's requirements and the specific needs of the box function (Figure 5). Prefabricated panels consist of a metal C steel structure that supports OSB panels on both sides, treated internally to prevent steam and condensation. Inside, stone wool or wood fiber insulation ensures thermal and acoustic performance.

To verify the thermal and internal comfort of the system, this paper examines different configurations of thermal insulation. The insulation materials were selected based on their economic value and ease of availability in the market.

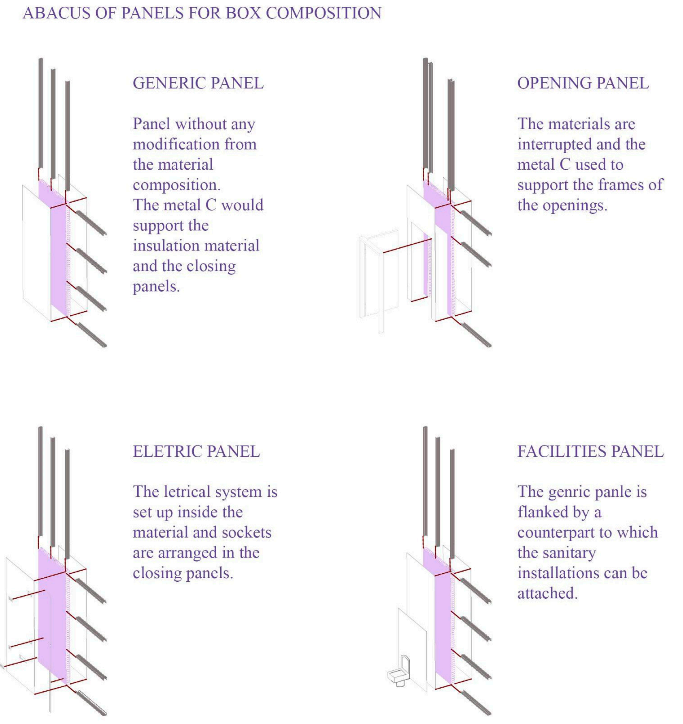
Despite the modularity of the system, the customization of the spaces can generate flexibility in the environment and create a psychologically friendly atmosphere for users.

The system is economical and easy to construct due to the use of commonly available materials tailored to the specific situation. An economic evaluation of the system was conducted and reported in previous work [28].



(**a**) (**b**)

Figure 4. The technological prototype is divided into a box and platform. (**a**) Three-dimensional visualization of the technological system of the platform. (**b**) Three-dimensional visualization of the technological system of the box.


ABACUS OF PANELS FOR BOX COMPOSITION

GENERIC PANEL

Panel without any modification from the material composition. The metal C would support the insulation material and the closing panels.

OPENING PANEL

The materials are interrupted and the metal C used to support the frames of the openings.

ELETRIC PANEL

The letrical system is set up inside the material and sockets are arranged in the closing panels.

FACILITIES PANEL

The genric panle is flanked by a counterpart to which the sanitary installations can be attached.

Figure 5. The functional abacus of panels. Three-dimensional visualization of the different types of panels cataloged according to their function. In order: classic panel, operable panel, sanitary panel, electric panel.

4. Energy Analysis

This paper aims to perform an energy analysis of the system, specifically to quantify the mutual benefits between the common area and the box system.

The analyses focus particularly on the indoor well-being of two distinct areas: the platform, which is not equipped with a heating system and is intended as a buffer space, and the boxes, which are heated. This analysis is significant for two primary reasons.

Firstly, it seeks to assess the internal comfort of the system in both the doctor's offices and the platform, where homeless individuals and other users can spend time during the day. Creating a livable environment is crucial for supporting emergency victims and people in distress, as it helps them build resilience and social networks, which are important health determinants.

Secondly, it aims to highlight the passive properties of the materials, which were selected based on cost-effectiveness and market availability.

4.1. Climate Definition

The study examines the performance of the structure under two extreme weather conditions in Italy. Simulations have been conducted to investigate the year-round behavior of the structure in Palermo, Sicily (Southern Italy), and Bolzano, Trentino-Alto Adige (Northern Italy) (Table 2). Additionally, the impact of the buffer zone of the platform on the boxes was assessed, as well as the effect of the heated zone of the boxes on the platform.

Table 2. Climate reference, weather data input, and general data of the case study sites.

	Bolzano	**Palermo**
Weather file from energyplus.net/weather	Bolzano—ITA IGDG WMO# = 160,200	PALERMO—ITA IWEC WMO# = 164,050
Latitude	46.47	38.18
Longitude	11.33	13.10
Elevation	791 ft	112 ft

Furthermore, a simulation was performed without the external envelope (polycarbonate panels) on the platform to enhance natural ventilation, which is anticipated to be more effective in the southern climatic zone.

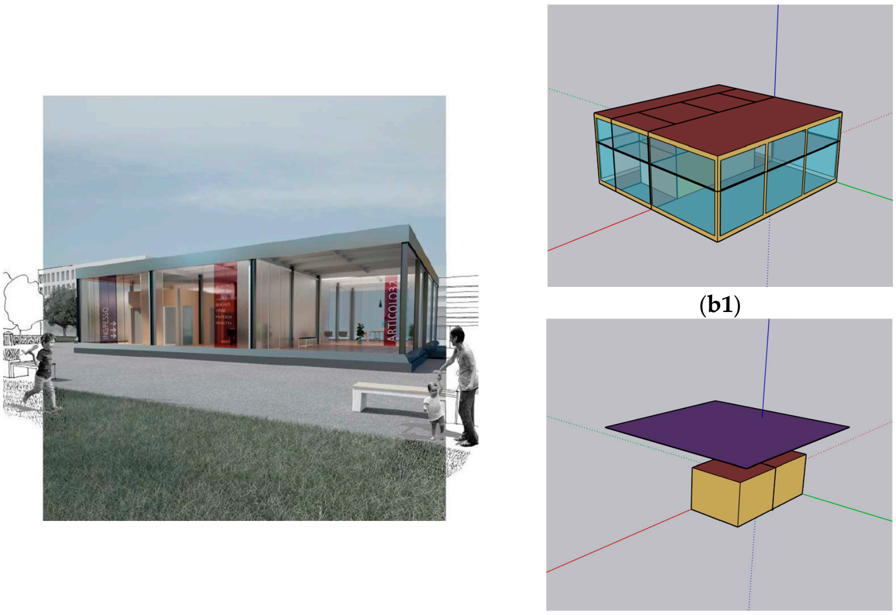
To address the overheating issue in Palermo, two scenarios were evaluated by considering 50% of the external polycarbonate panel envelope operable. Additionally, in both locations, simulations were conducted to improve the performance of the polycarbonate panels by using double panels with an air gap.

Table 2 displays the data for each geographic area.

4.2. Definition of the Model

The energy model differs from the architectural model in its classification and categorization of elements. Specifically, the energy model treats rooms as distinct thermal zones but does not account for architectural features such as pillars, walls, or floors. Additionally, the energy model simplifies geometry by representing rectangular rooms, which leads to the platform and boxes being depicted as extruded rectangles in the plan. Due to the large dimensions and the inclusion of boxes on the platform, it was necessary to subdivide it into several rectangles. Each wall was assigned properties based on the architectural model: walls separating the boxes were modeled with sandwich panel characteristics, while external platform walls were classified as steel structures with polycarbonate 'windows'. Internal platform walls, due to their geometry, were treated as air walls.

Figure 6a,b1,b2 illustrate the architectural and energy models, respectively, divided into thermal zones. Figure 6b1 demonstrates energy consumption and indoor temperature with the platform protecting the box system using operable polycarbonate panels as vertical closures. In contrast, Figure 6b2 simulates the platform solely as a shading device for the box system, without polycarbonate panels, assuming that cross ventilation is more significant for protection against adverse weather conditions.



(**b1**)

(**a**) (**b2**)

Figure 6. (**a**) SketchUp model used in the OpenStudio simulations. Render of the architectural model (**b1**) The first option considers the box and platform as two different thermal zones that communicate with each other. The outermost zone is the platform, which lacks a heating system and is protected from bad weather conditions solely by polycarbonate panels (represented as windows in the graphic). The innermost zone is the box, which is heated to ensure optimal thermal conditions in the doctor's office. The model was created by dividing different thermal areas into extruded rectangular spaces. All walls within the same thermal zone, formed during the extrusion process, were treated as air walls, thereby preserving the thermal properties of both the box and platform areas. (**b2**) The second option regards the platform system as a shading device by removing the external polycarbonate panels. In this scenario, the platform remains a social space but is treated as an external area outside the building.

The architectural model includes an external platform roof, which is not represented in the energy model, as not relevant for inner thermal comfort. In the energy model, the roof is treated as part of the external environment and simplified into a regular form. This simplification does not impact the simulation results, which focus on internal thermal comfort, heat input, and material performance evaluation. As described below, loads were scaled proportionally to the initial model.

4.3. Materials Characterization and Input Data

As previously described, two distinct thermal zones have been considered: the boxes, which are treated as heated zones, and the platform, which is not equipped with heating. Additionally, the energy analysis accounts for the contributions of users.

Unlike the stringent requirements of hospital settings, the boxes are classified as offices intended for two people, with an expected activity level of 90 W/person from 8 a.m. to 2 p.m. The heating systems are designed to activate when the temperature drops below 15 °C before the service opens at 6 a.m. and to reach 21 °C during service hours. No cooling systems are included in the design.

The platform is designed to accommodate 20 people, proportional to the dimensions of the prototyping model used for the energy analysis. It is considered usable throughout the day, with peak activity from 8 a.m. to 7 p.m., generating an energy output of 90 W/person.

As mentioned earlier, the material properties have been detailed in the architectural model. The walls and ceiling of the boxes are constructed from OSB and mineral wool sandwich panels. The box structure utilizes aluminum profiles, while the platform structure is made from stainless steel S275. The panel system variant was chosen to compare the efficiency of a low-density material, such as wood fiber.

The platform features operable polycarbonate panels to meet users' needs, particularly during the winter months in northern regions. Polycarbonate was selected for safety reasons, as glass windows are not recommended in public spaces due to their weight. Additionally, polycarbonate is a lightweight material that is easy to construct and cost-effective.

The ground floor is made of wood–concrete panels for both the boxes and the platform, while the platform roof is constructed from sandwich panels composed of aluminum and XPS.

Table 3 presents the properties of the materials used in the simulation and provides the values required to run the simulation:

Table 3. Materials' properties used during the simulation.

	s [m]	λ [W/mK]	ρ [kg/m^3]	C_s [J/KgK]
OSB	0.012	0.10	530	1000
Mineral Wool	0.08	0.034	80	1000
Wood Fiber	0.08	0.037	110	2100
XPS	0.12	0.036	32	1700
Wood–concrete	0.40	0.26	1350	1880
Polycarbonate	0.06	0.21	200	1170
Aluminum	0.002	172	2800	962
S275	0.21	45	7850	502

5. Results

This study compares several simulations to evaluate the efficiency of the model, focusing on two climatic regions: Bolzano in northern Italy and Palermo in southern Italy. Various technical solutions are assessed using the OpenStudio 1.7.0 software, which calculates the number of hours at specific temperatures throughout the year.

This approach was instrumental in testing different design hypotheses aimed at enhancing the thermal comfort and overall energy efficiency of the system, thereby assisting in the process of defining a possible material and technological solution for the prototype.

5.1. Simulation Results—Bolzano Area

5.1.1. Bolzano—Simulation 1

Table 4 presents the values from the simulation conducted in Bolzano. In this scenario, the box is insulated with mineral wool, and the platform is constructed with a single layer of polycarbonate panels (Figure 7) to protect against bad weather conditions. The mean relative humidity recorded in the box is 14.2%, while in the platform it is 22.7%. The mean temperature in the box is 68.9 °F (20 °C), while in the platform it is 61.4 °F (16.3 °C).

The table below details the different temperature ranges recorded for each thermal zone.

Table 4. Bolzano site. Box: mineral wool insulation panels. Platform: one-layer polycarbonate panels. Hours spent in each temperature range in one year.

	<56 [F]	56–61 [F]	61–66 [F]	66–68 [F]	68–70 [F]	70–72 [F]	72–74 [F]	74–76 [F]	76–78 [F]	78–83 [F]	83–88 [F]	≥88 [F]
TZ-BOX	0	1874	845	874	447	1818	707	610	868	493	216	8
TZ-PLATFORM	3556	601	499	631	305	298	278	288	515	470	385	934

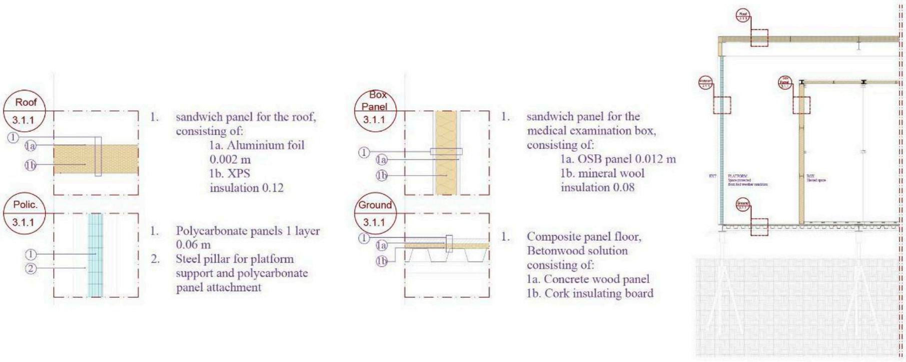


Figure 7. Graphitization of materials in the various closures analyzed and architectural section in the simulation Bolzano 1.

5.1.2. Bolzano—Simulation 2

In this second simulation, a different type of insulation was considered. Table 5 presents the values obtained from the simulation conducted in Bolzano, where the box is insulated with wood fiber and the platform is constructed with a single layer of polycarbonate panels (Figure 8). The mean relative humidity recorded in the box is 14.1%, while in the platform it is 22.7%. The mean temperature in the box is 69 °F (20.5 °C), whereas in the platform it remains at 61.4 °F (16.3 °C).

Table 5. Bolzano site. Box: wooden fiber insulation panels. Platform: one-layer polycarbonate panels. Hours spent in each temperature range in one year.

	<56 [F]	**56–61 [F]**	**61–66 [F]**	**66–68 [F]**	**68–70 [F]**	**70–72 [F]**	**72–74 [F]**	**74–76 [F]**	**76–78 [F]**	**78–83 [F]**	**83–88 [F]**	**≥88 [F]**
TZ-BOX	0	1804	861	862	442	1798	711	639	872	521	244	6
TZ-PLATFORM	3554	594	500	618	321	303	278	286	526	479	379	992

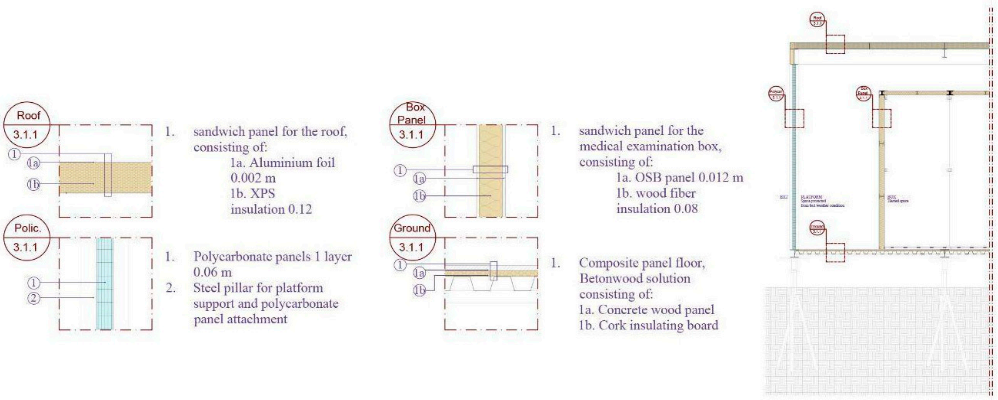


Figure 8. Graphitization of materials in the various closures analyzed and architectural section in the simulation Bolzano 2.

5.1.3. Bolzano—Simulation 3

In this simulation, the box is insulated with mineral wool (Table 6). The thermal properties of the platform are enhanced by employing two layers of polycarbonate panels separated by a closed air gap, which increases the thermal mass and improves protection against adverse weather (Figure 9).

Table 6. Bolzano site. Box: mineral wool insulation panels. Platform: double-layer polycarbonate panels and closed air gap. Hours spent in each temperature range in one year.

	<56 [F]	**56–61 [F]**	**61–66 [F]**	**66–68 [F]**	**68–70 [F]**	**70–72 [F]**	**72–74 [F]**	**74–76 [F]**	**76–78 [F]**	**78–83 [F]**	**83–88 [F]**	**≥88 [F]**
TZ-BOX	0	1955	915	959	578	2079	737	544	607	359	27	0
TZ-PLATFORM	3518	654	542	624	338	367	316	326	582	483	419	591

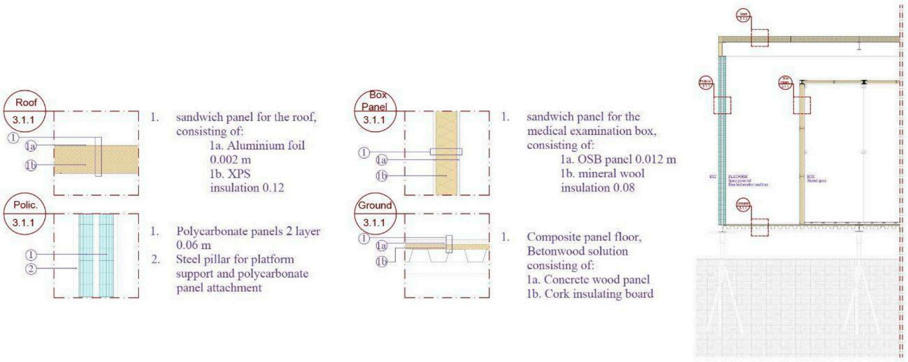


Figure 9. Graphitization of materials in the various closures analyzed and architectural section in the simulation Bolzano 3.

The mean relative humidity recorded in the box is 14.5%, whereas in the platform it is 22.6%. The mean temperature in the box is 68 °F (20 °C), while in the platform it is 60.8 °F (16 °C).

5.2. Simulation Results—Palermo Area

5.2.1. Palermo—Simulation 1

The same simulations have been run in a southern area of Italy. The table presents the values obtained from the simulation conducted in Palermo (Table 7). In this scenario, the box is insulated with mineral wool, and the platform is constructed with a single layer of polycarbonate panels (Figure 10), which remain closed throughout the simulation period.

Table 7. Palermo site. Box: mineral wool insulation panels. Platform: one-layer polycarbonate panels. Hours spent in each temperature range in one year.

	<56 [F]	**56–61 [F]**	**61–66 [F]**	**66–68 [F]**	**68–70 [F]**	**70–72 [F]**	**72–74 [F]**	**74–76 [F]**	**76–78 [F]**	**78–83 [F]**	**83–88 [F]**	**≥88 [F]**
TZ-BOX	0	0	275	1223	661	1364	534	512	1059	1241	1295	596
TZ-PLATFORM	157	1054	765	693	308	336	359	311	685	786	767	2539

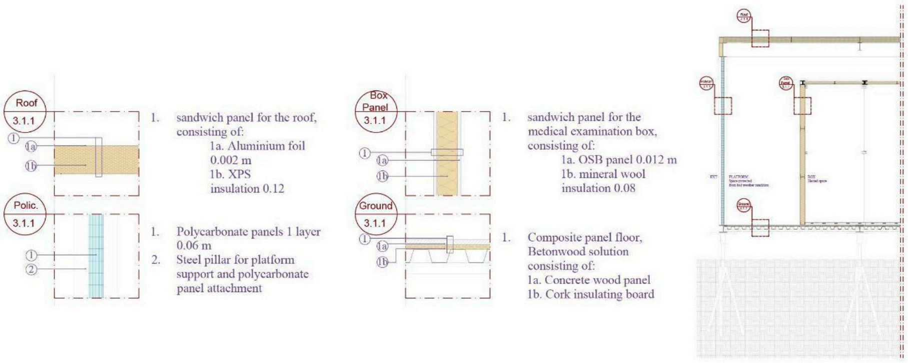


Figure 10. Graphitization of materials in the various closures analyzed and architectural section in the simulation Palermo 1.

The mean relative humidity recorded in the box is 37.5%, while in the platform it is 34.4%. The mean temperature in the box is 68.2 °F (20.1 °C), while in the platform it is 72.9 °F (22.7 °C).

5.2.2. Palermo—Simulation 2

A common issue in Palermo is overheating, attributable to its Mediterranean climate, which contrasts with the situation in Bolzano where overheating is not a concern. To address this, the simulation tests (Table 8) a hypothesis for mitigating heat in the buffer area by utilizing operable polycarbonate panels covering 50% of the total envelope surface. In this scenario, the box is insulated with mineral wool, and the platform is constructed with a single layer of polycarbonate panels (Figure 11).

Table 8. Palermo site. Box: mineral wool insulation panels. Platform: one-layer polycarbonate panels and openable windows. Hours spent in each temperature range in one year.

	<56 [F]	**56–61 [F]**	**61–66 [F]**	**66–68 [F]**	**68–70 [F]**	**70–72 [F]**	**72–74 [F]**	**74–76 [F]**	**76–78 [F]**	**78–83 [F]**	**83–88 [F]**	**≥88 [F]**
TZ-BOX	0	0	282	1247	828	1768	1017	753	1021	769	739	336
TZ-PLATFORM	157	1059	794	860	637	700	582	516	1243	683	289	1240

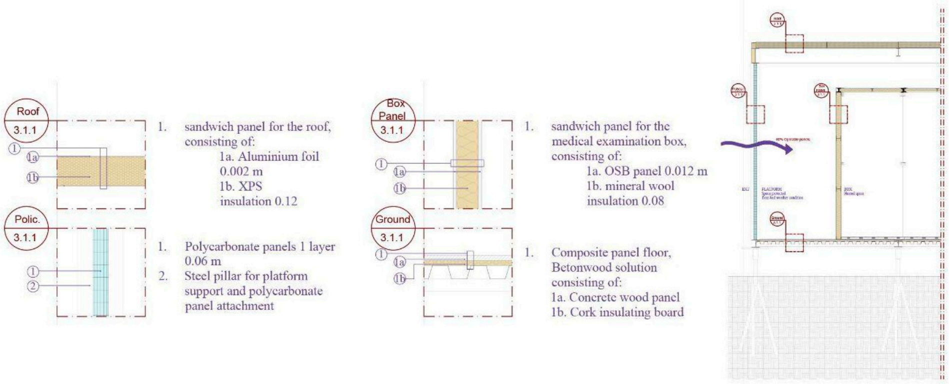


Figure 11. Graphitization of materials in the various closures analyzed and architectural section in the simulation Palermo 2.

The mean relative humidity recorded in the box is 31.9%, whereas in the platform it is 57.7%. The mean temperature in the box is 75.3 °F (23 °C), while in the platform it is 73.6 °F (23.1 °C).

5.2.3. Palermo—Simulation 3

The same simulation, with 50% of the polycarbonate panels on the platform open, was conducted using wood fiber panels for insulation in the box (Figure 12) (Table 9).

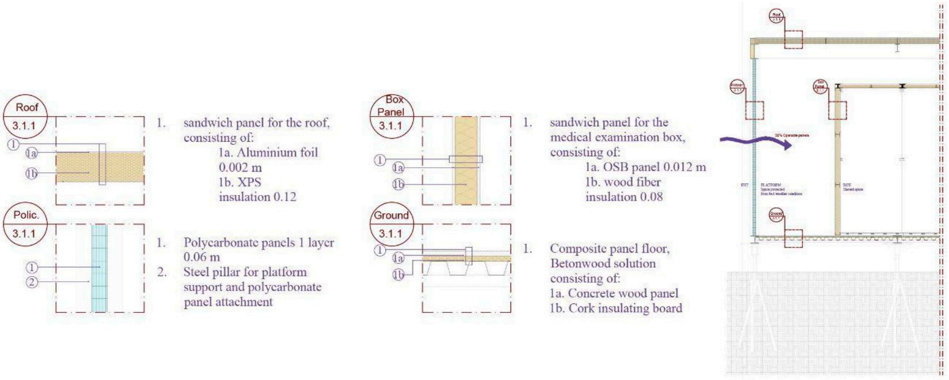


Figure 12. Graphitization of materials in the various closures analyzed and architectural section in the simulation Palermo 3.

Table 9. Palermo site. Box: wooden fiber insulation panels. Platform: one-layer polycarbonate panels and openable windows. Hours spent in each temperature range in one year.

	<56 [F]	**56–61 [F]**	**61–66 [F]**	**66–68 [F]**	**68–70 [F]**	**70–72 [F]**	**72–74 [F]**	**74–76 [F]**	**76–78 [F]**	**78–83 [F]**	**83–88 [F]**	**≥88 [F]**
TZ-BOX	0	0	141	1222	896	1775	1055	783	975	758	770	385
TZ-PLATFORM	147	1043	790	881	641	695	600	530	1240	672	292	1229

The mean relative humidity recorded in the box is 31.6%, while in the platform it is 58.1%. The mean temperature in the box is 73.7 °F (23.2 °C), whereas in the platform it is 73.6 °F (23.1 °C).

5.2.4. Palermo—Simulation 4

The final simulation in Palermo involves the box insulated with mineral wool and the platform constructed with two layers of polycarbonate panels (Figure 13). Similar to the simulation conducted in Bolzano, the polycarbonate panels in this scenario are non-operable, and the air cavity between the panels remains closed (Table 10). This setup aims to evaluate the effect of the air gap on increasing the thermal mass.

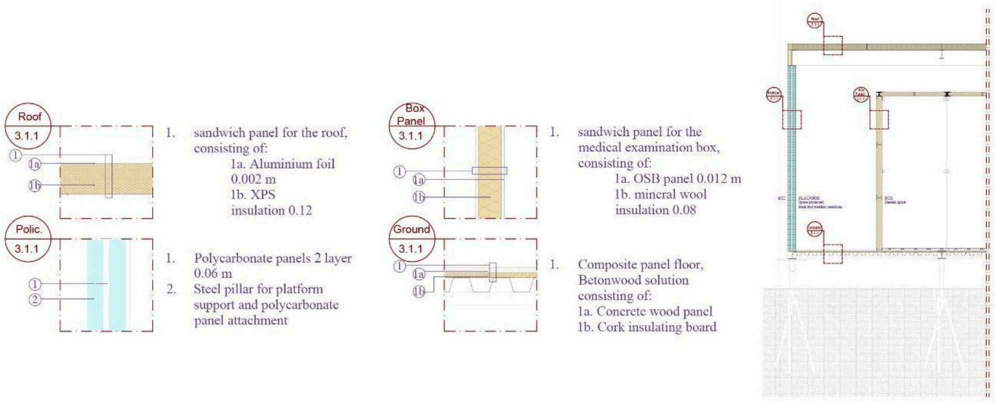


Figure 13. Graphitization of materials in the various closures analyzed and architectural section in the simulation Palermo 4.

Table 10. Palermo site. Box: mineral wool insulation panels. Platform: two layers of polycarbonate panels and a closed air gap. Hours spent in each temperature range in one year.

	<56 [F]	**56–61 [F]**	**61–66 [F]**	**66–68 [F]**	**68–70 [F]**	**70–72 [F]**	**72–74 [F]**	**74–76 [F]**	**76–78 [F]**	**78–83 [F]**	**83–88 [F]**	**≥88 [F]**
TZ-BOX	0	0	431	1526	735	1439	548	554	1211	1475	822	19
TZ-PLATFORM	127	1134	844	755	350	386	377	351	733	827	802	2074

The mean relative humidity recorded in the box is 31.9%, whereas in the platform it is 31.7%. The mean temperature in the box is 73.5 °F (23 °C), while in the platform it is 75.8 °F (24.3 °C).

5.3. Simulation Results—No Platform as Thermal Zone

The final simulation, conducted for both sites, assumes that the platform is not functioning as a thermal zone but rather as a shading device (Table 11). Consequently, the polycarbonate panels are not installed (Figure 14). From an architectural perspective, this configuration implies that the common area on the platform is treated as an external, open space.

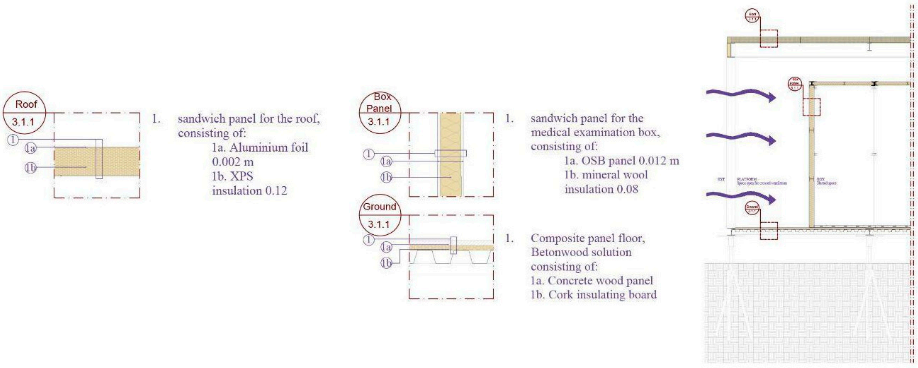


Figure 14. Graphitization of materials in the various closures analyzed and architectural section in the simulation without polycarbonate panels defining the buffer area of the platform.

In Bolzano, the mean relative humidity recorded is 15.3%, with a mean temperature is 66.4 °F (19.1 °C). On the other hand, in Palermo, the mean relative humidity is 35.2%, and the mean temperature is 70.5 °F (21.4 °C).

The table below presents the various temperature ranges recorded for each site.

Table 11. Bolzano and Palermo site. Box: mineral wool insulation panels. Platform: no polycarbonate panels (open platform). Hours spent in each temperature range in one year.

	<56 [F]	**56–61 [F]**	**61–66 [F]**	**66–68 [F]**	**68–70 [F]**	**70–72 [F]**	**72–74 [F]**	**74–76 [F]**	**76–78 [F]**	**78–83 [F]**	**83–88 [F]**	**≥88 [F]**
BOLZANO	0	2336	933	1359	570	2478	431	284	263	106	0	0
PALERMO	0	331	1157	1336	706	1797	666	679	1284	740	64	0

6. Discussion and Conclusions

This study investigates the energy performance of a modular box system designed for healthcare facilities, specifically addressing the needs of individuals requiring care who are not regular citizens.

Based on preliminary analyses of existing models and structures operating in Italy, a new modular concept has been developed to address the issue of assistance in several situations, from emergency management to routine operations, integrating with existing contexts. The design also considers the psychological needs of users by incorporating open areas dedicated to humanizing services for indigent individuals who require a place to spend the day, in this sense, the model represents an advancement over traditional emergency structures. To evaluate the model's effectiveness in different climatic contexts, two extreme scenarios were examined: Bolzano (cold climate) and Palermo (hot climate).

The main conclusions are summarized as follows:

- The system, which does not include a cooling system and only provides heating in the box area, generally maintains acceptable temperature ranges across simulations. In Bolzano, the box temperatures are approximately 68 °F (20 °C), while the platform temperatures are around 60.8 °F (16 °C). In Palermo, the Mediterranean climate leads to more variable results: the box temperature is typically 73.4 °F (23 °C), though it reaches 68 °F (20 °C) in the first simulation. The platform temperature averages 73.4 °F (23 °C), but rises to 75.2 °F (24 °C) in simulation 4 due to the double layer of polycarbonate panels.
- Simulations assessed various insulating materials within the sandwich panels, including mineral wool and wood fiber, with different thermal properties and densities. Although wood fiber performs better in hot climates, the annual temperature variations are relatively minor in both climatic zones.
- The platform, designated as a buffer zone without a heating system, can reduce equipment needs. In the northern site (Bolzano), results in Table 4 show that the

platform area spends approximately 3550 h at temperatures around 56 °F (13 °C), which is considered a good outcome. However, the use of double polycarbonate panels results in a slight improvement, with 3518 h at 56 °F (Table 6).

- On the other hand, in Palermo, where summer temperatures are very high, the risk of overheating is evident. Table 7 shows that the platform (common area) exceeds 88 °F (32 °C) for 2539 h.
- Simulation 2 in Palermo indicates that simple measures, such as opening windows or increasing the mass of the polycarbonate panels, can improve results. Operable windows reduce overheating above 88 °F (31 °C) from 2539 h to 1240 h in the platform (Table 8). Additionally, in the final simulation (Table 11), where the platform is open and functions as a shading device for the boxes, the impact on these is notable, with a significant reduction in heating hours above 83 °F.
- In Bolzano (cold climate), using a closed platform is advantageous as it protects internal structures and improves thermal exchanges. Table 4 shows that the platform, being closed for the simulation, results in 1874 h at 56–61 °F (13–16 °C) compared to 2336 h when external panels are removed (Table 11)
- On the other hand, in Palermo (hot climate), the simulations indicate that omitting the panels enhances air circulation, reducing extreme overheating to 83–88 °F (28–31 °C) from 1295 h (739 if operable) (see Table 7) to 64 h and overheating above 88 °F (31 °C) from 596 h (336 if operable) to 0 h, as seen in Table 11.

Finally, given the critical importance of the project's economic feasibility and ease of assembly, the prototype has been designed to meet the requirements for both flexibility and sustainability.

Future research should explore the integration of higher-performance materials, potentially prioritizing functionality over cost. Additionally, further studies could investigate the implementation of a comprehensive facilities management system surrounding the model.

Author Contributions: "Introduction" L.M.; "Materials and Methods" S.B.; "Model Analysis" L.M.; "Results" S.B. and L.M.; "Discussion" and "Conclusions" have been written by both authors. All authors have read and agreed to the published version of the manuscript.

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References

1. Hosseini, S.M.A.; Farahzadi, L.; Pons, O. Assessing the sustainability index of different post-disaster temporary housing unit configuration types. *J. Build. Eng.* **2021**, *42*, 102806. [CrossRef]
2. Wallemacq, P.; House, R.; Economic Losses, Poverty & Disaster, 1998–2017. CRED & UNISDR. Available online: https://www.preventionweb.net/files/61119_credeconomiclosses.pdf (accessed on 26 April 2024).
3. EEA Technical Report. *Mapping the Impacts of Natural Hazards and Technological Accidents in Europe*; Technical report No 13; EEA: Copenhagen, Denmark, 2010; ISSN 1725-2237.
4. Al-Atrash, F.Z.; Hamdan, M.; Mualla, R. Energy efficient shelter for displaced person: Towards sustainable camps. *Bauphysik* **2023**, *45*, 3. [CrossRef]
5. Bologna, R.; Terpolilli, C. *Emergenza del Progetto. Progetto dell'Emergenza. Architetture Con-Temporaneità*; Jodidio, P., Ed.; Federico Motta Editore: Milano, Italy, 2005; Temporary Architecture Now!; TASCHEN GMBH: Bonn, Germany, 2011.
6. Falasca, C.C. *Architetture ad Assetto Variabile. Modelli Evolutivi per L'habitat Provvisorio*; Tecnologia e Progetto 3; Alinea Editrice: Firenze, Italy, 2000.
7. Paparella, R.; Caini, M. Sustainable Design of Temporary Buildings in Emergency Situations. *Sustainability* **2022**, *14*, 8010. [CrossRef]

8. Montalbano, G.; Santi, G. Sustainability of Temporary Housing in Post-Disaster Scenarios: A Requirement-Based Design Strategy. *Buildings* **2023**, *13*, 2952. [CrossRef]
9. Cascone, S.M.; Caporlingua, M.; Russo, G.; Tomasello, N. La "prefabbricazione per l'emergenza": Excursus storico dalla nascita alle moderne applicazioni. In Proceedings of the 3 Convegno Internazionale "Storia dell'Ingegneria", Napoli, Italy, 23–24 April 2018.
10. UNHCR. Available online: https://emergency.unhcr.org/emergency-assistance/shelter-camp-and-settlement/shelter-and-housing/emergency-shelter-solutions-and-standards (accessed on 26 April 2024).
11. Potangaroa, R. Climate responsive design tools for emergency shelter. In *Hand-Book for Emergencies*; UNHCR: Ginevra, Switzerland, 2006.
12. Manfield, P. *Modeling of a Cold Climate Emergency Shelter: Prototype and comparison with the United Nations Winter Tent*; Martin Centre: Cambridge, UK, 2000.
13. Cornaro, C.; Sapori, D.; Bucci, F.; Pierro, M.; Corrado, G. Thermal performance analysis of an emergency shelter using dynamic building simulation. *Energy Build.* **2015**, *88*, 122–134. [CrossRef]
14. Lv, T.; Liu, B.; Liu, R.; Zhu, L.; Huo, Y.; Ji, M. Construction and Electrothermal Performance Evaluation of a Solar-Powered Emergency Shelter. *Energies* **2024**, *17*, 118. [CrossRef]
15. Ribera, F.; Regno, R.D.; Cucco, P. New Frontiers of Temporary Buildings. Passive housing Modules. *AGATHÓN Int. J. Archit. Art Des.* **2018**, *4*, 159–168.
16. Félix, D.; Monteiro, D.; Branco, J.M.; Bologna, R.; Feio, A. The role of temporary accommodation buildings for post-disaster housing reconstruction. *J. Hous. Built Environ.* **2015**, *30*, 683–699. [CrossRef]
17. Mayo, A.J.; Nohria, N. *Their Time: The Greatest Business Leaders of the Twentieth Century*; Harvard Business Review Press: Cambridge, MA, USA, 2005.
18. Levinson, M. *The Box: How the Shipping Container Made the World Smaller and the World Economy Bigger*; Princeton University Press: Princeton, NJ, USA, 2006.
19. Eberhardt, L.C.M.; Birkved, M.; Birgisdottir, H. Building design and construction strategies for a circular economy. *Archit. Eng. Des. Manag.* **2022**, *18*, 93–113. [CrossRef]
20. Park, B.; Cho, J.; Jeong, Y. Thermal Performance Assessment of Flexible Modular Housing Units for Energy Independence Following Disasters. *Sustainability* **2019**, *11*, 5561. [CrossRef]
21. Moon, J. *A Study on the Planning Method Temporary Dwellings for Sufferers from a Disaster*; Decree of the Yonsei University: Seoul, Republic of Korea, 2007.
22. Košir, M.; Iglič, N.; Kunič, R. Optimisation of heating, cooling and lighting energy performance of modular buildings in respect to location's climatic specifics. *Renew. Energy* **2018**, *129*, 527–539. [CrossRef]
23. Al Dakheel, J.; Tabet Aoul, K. Building applications, opportunities and challenges of active shading systems: A state-of-the-art review. *Energies* **2017**, *10*, 1672. [CrossRef]
24. Marin, P.; Saari, M.; de Gracia, A.; Zhu, X.; Farid, M.M.; Cabeza, L.F.; Ushak, S. Energy savings due to the use of PCM for relocatable lightweight buildings passive heating and cooling in different weather conditions. *Energy Build.* **2016**, *129*, 274–283. [CrossRef]
25. Zubair, M.; Bilal Awan, A.; Al-Ahmadi, A.; Abo-Khalil, A. NPC based design optimization for a net zero office building in hot climates with PV panels as shading device. *Energies* **2018**, *11*, 1391. [CrossRef]
26. Pan, W.; Zhang, Z. Evaluating Modular Healthcare Facilities for COVID-19 Emergency Response—A Case of Hong Kong. *Buildings* **2022**, *12*, 1430. [CrossRef]
27. Smolova, M.; Smolova, D. Emergency architecture. Modular construction of healthcare facilities as a response to pandemic outbreak. *E3S Web Conf.* **2021**, *274*, 01013. [CrossRef]
28. Brunoro, S.; Mensi, L. A Modular Structure for Immediate and Transitory Interventions to Guarantee Access to Basic Healthcare in Italy. *Sci* **2023**, *5*, 17. [CrossRef]
29. World Health Organization. Available online: https://www.who.int/news-room/questions-and-answers/item/determinants-of-health (accessed on 26 April 2024).
30. Hay, A.; Gomez-Palacio, A.; Martyn, N. Planning resilient communities. In *Resilience and Risk, NATO Science for Peace and Security Series C: Environmental Security*; Linkov, I., Palma-Oliveira, J., Eds.; Springer: Dordrecht, The Netherlands, 2017; pp. 313–326. [CrossRef]
31. Hall, E.T. *La Dimensione Nascosta che Cosa è la Prossemica?* Bompiani: Florence, Italy, 1969.